STEM Futures and Practice,

Can We Teach STEM in a More Meaningful and Integrated Way?

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Abstract: *Integrating Science, Technology, Engineering and Mathematics (STEM) subjects can be engaging for students, can promote problem-solving and critical thinking skills and can help build real-world connections. However, STEM has long been an area of some confusion for some educators. While they can see many of the conceptual links between the various domains of knowledge they often struggle to meaningfully integrate and simultaneously teach the content and methodologies of each these areas in a unified and effective way for their students. Essentially the question is; how can the content and processes of four disparate and yet integrated learning areas be taught at the same time? How can the integrity of each of the areas be maintained and yet be learnt in a way that is complementary?*

Often institutional barriers exit in schools and universities to the integration of STEM. Organizationally, at a departmental and administrative level, the teaching staff may be co-located, but when it comes to classroom practice or the teaching and learning of these areas they are usually taught very separately. They are usually taught in different kinds of spaces, in different ways (using different pedagogical approaches) and at different times. But is this the best way for students to engage with the STEM areas of learning? How can we make learning more integrated, meaningful and engaging for the students?

Keywords: STEM Education, integrated learning, curriculum design, real life problem solving, PBL

1. Introduction

Integrating Science, Technology, Engineering and Mathematics (STEM) helps students connect relevant skills to the use of the skills in real world applications by providing valuable learning contexts (Brophy, Klein, Portsmor, & Rogers, 2008). The STEM subjects are closely related to each other and the integration of these subjects can help students develop relevant knowledge, concepts and skills (Tseng, Chang, Lou, & Chen, 2011). However, the continued separation of the STEM disciplines, in terms of how, when and where they are taught continues to occur in your schools and universities for a number of administrative and organisational reasons (Herschbach, 2011). But is this the best way of teaching them and are there some viable alternatives which we should consider? There are many connections between the concepts that are taught in these disciplines. For example, in mathematics classrooms, we may be focusing on ratios. In science classrooms the lesson may be on the concentration of different solutions. Technology activities may be based on mixing ingredients in a healthy meal. In engineering, the focus may be on the exploration of different concrete mixes. There is one common thread between these concepts and that is ratios (Figure 1).

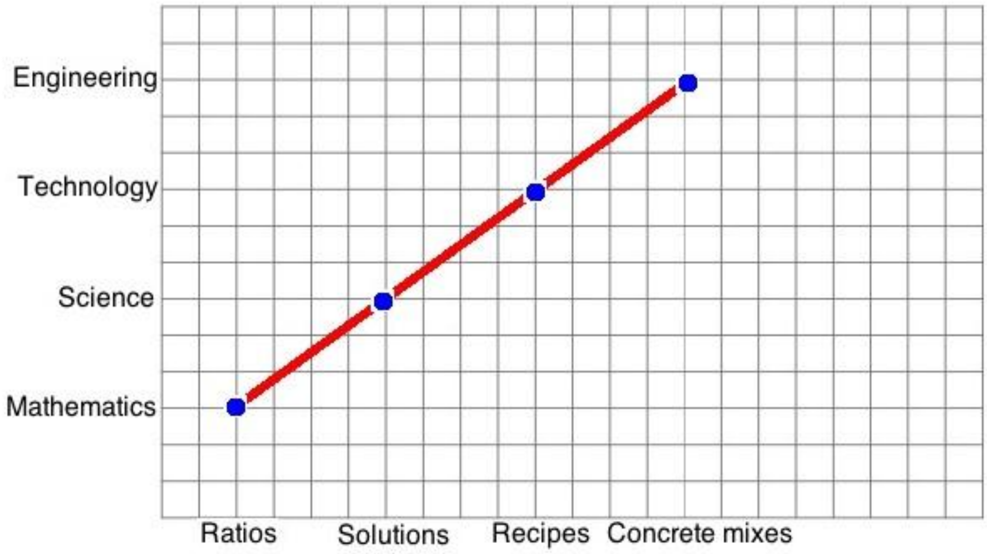

Figure 1. Inter-relationship between concepts across STEM disciplines

Such connections between these disciplines need to be further harnessed. One alternative is a project-based learning (PBL) approach that focuses on practical activities where student teams work together on projects and develop a shared understanding (ChanLin, 2008; Krajcik, Czeniak, & Berger, 1999). PBL is a learner-centered approach where students are encouraged to integrate knowledge, take responsibility for their learning and work in teams to investigate real issues and construct products. PBL has been shown to be effective in increasing motivation and higher order thinking skills (Blumenfeld et al., 1991). A PBL approach can facilitate the integration of STEM knowledge and assist students to develop their problem solving abilities and knowledge integration. Integrating STEM into a PBL approach can help students understand the relationship between their learning and the real-world applications (Hmelo-Silver 2004; Salomon & Perkins 1989).

One of the main reasons for the continued separation of the STEM disciplines comes from the fact that the teachers (especially in high school and universities) come from different discipline backgrounds and each values their domain of knowledge as a separate area of learning with its own history and curriculum practices (Herschbach, 2011). Even if many acknowledge that there are conceptual and real world links between the areas they struggle with the strategies necessary to integrate the areas of learning meaningfully into an effective, cohesive and manageable learning program (Williams, 2011; Yaşar et al., 2006).

Yet in the 'real world', outside of STEM education, the domains and disciplines of STEM are often integrated (Herschbach, 2011). That is, people from all areas of STEM are asked to draw their ideas and thinking together to deliver real outcomes. For example, the design and construction of a bridge requires a range of personnel drawn from across the STEM disciplines. They need to know how to share and integrate their knowledge if they are to effectively and efficiently build the best possible bridge. If anyone of these areas fails then the outcomes of the project are in jeopardy and can be catastrophic for the users of the bridge. So how does this happen and can we use the processes and ideas of the 'real world' to drive our classroom practice and deliver real world learning for our students?

The answer is certainly yes. And this paper will examine three different models of implementation of PBL with the STEM agenda in the classroom. These models will propose different ways for teachers, and teams of teachers, to implement an integrated approach to STEM.

2. First Model: The Central Project Approach

The Central Project Approach is a teacher-led approach where a teacher, or a team of teachers, integrates the STEM subjects around a central activity. With the Central Project Approach the teaching and learning processes can typically occur at two levels. Direct teaching and integrated problem solving/group work - Indirect learning episodes. In the Direct teaching section the students are still 'taught' in separate discipline based groups. This ensures that specific key concepts and ideas are addressed by the students and provides the teacher with the confidence that particular areas of valued content are addressed. Then through this process the students are exposed to Indirect learning episodes where they are brought together in small teams to explore and construct their own designs which build upon their concepts through real life design challenges. The students are asked to collectively document their ideas and try to make links to the knowledge with they are developing in each of their direct teaching lessons. They are encouraged to share their learning and thoughts from their separate lessons and try to integrate these to synthesis their knowledge (Herschbach, 2011).

If we can take the simple and 'closed' example of a bridge to demonstrate how integrated STEM activities could evolve in a school or university setting. In the simplest way we can use the context of 'bridge design and engineering' as a context for multidisciplinary learning. Students drawn from different discipline areas focused around the one problem can each be asked to work and contribute their ideas and knowledge to the design task. For example, in physics students might examine 'stresses and loading' equations associated with the bridge and develop an understanding of the algorithms and knowledge needed to effectively analyze and fault find the integrity of the bridge's structure. In the Technology area the students could look at the design elements and typical structures within bridges and analyzing the design processes which are typically followed in bridge design and construction through the analysis of a video case study or discussions with a bridge engineer. In Mathematics students could also look at load analysis and algorithms for testing different building configurations of particular materials.

The diagram of Model 1 (see Figure 2) represents the Central Project Approach idea with each subject having a section of 'discipline based time' but with a core integrating activity providing an opportunity to share, integrate and further develop their thinking and ideas in a problem based environment. In many ways this models the ways in which real design professionals, engineers, architects and scientists work together to solve problems and develop creative design solutions to real problems.

This model could also work in a slightly different way across a semester with the students being taught separately in their subject domains for the first part of the semester and then coming together for all of their classes in the last half of the semester to design and work on a range of projects which help to demonstrate their learnings.

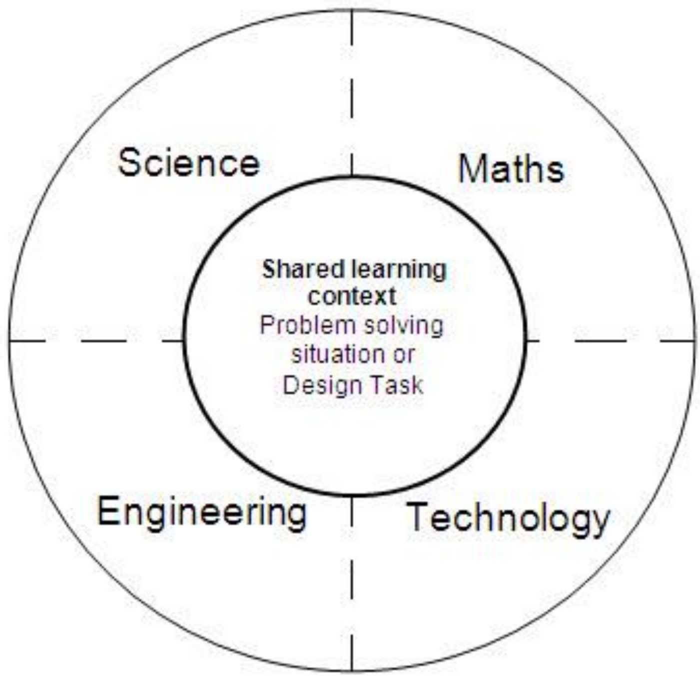

Figure 2: The Central Project Approach (Model 1)

3. Second Model: Student Led Projects Approach

While the first approach to the integration of STEM focuses on a teacher driven approach, where a team of teachers pre-plan the design task, the second is more student led. In this model the students are asked to design and develop their own projects (Bencze, 2010), each offering an opportunity to explore concepts and ideas associated with STEM concepts. This is a more open project model where the students have a range of creative design options (Figure 3). Typically the students are lead through a simple design process so that they understand the fundamental processes that they will need to follow when undertaking their own project. The students are then asked to form teams and to work on defining a project of interest to them. They then undertake the design process to design and realize their product. Various levels of guidance may be offered to the students to shape their thinking. For example, they may be asked to design and develop a time saving device for use around the house or to design and develop a product which might be used by a person with a disability. This still means that the students will be applying a range of concepts relating to the areas of STEM but the content that might be taught in class would not necessarily relate to the designs that the students are creating. This can be done as an integrated project where teams are developed a combination of students from different subjects relating to STEM or as a series of stand-alone projects where the students from different STEM areas work separately at different times, but perhaps come together to share their final design products across the STEM area – something like a science fair.

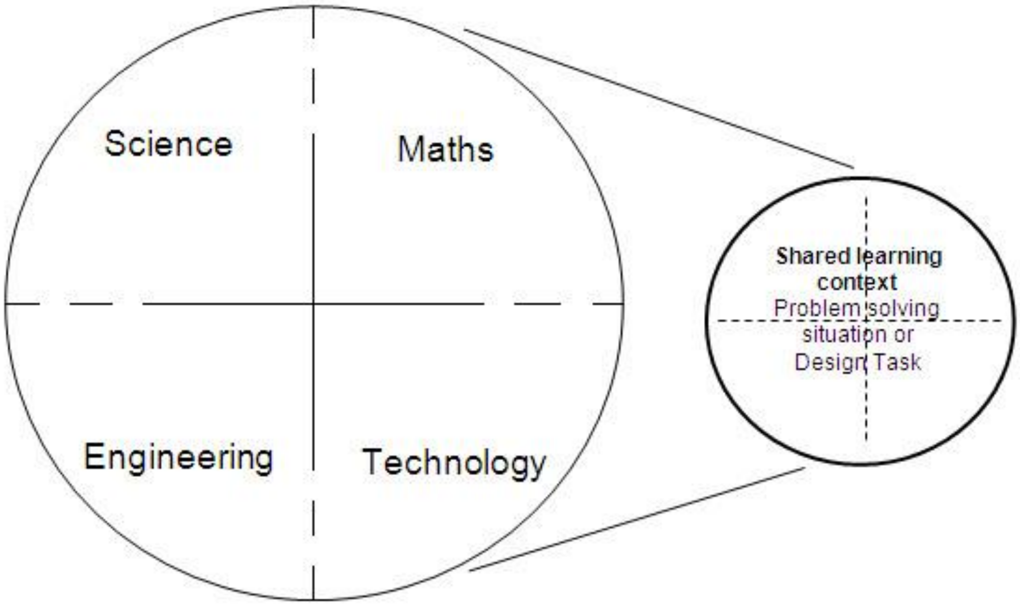

Figure 3: Student Led Projects Approach (Model 2)

4. Third Model – Using Student Led Projects as the Curriculum

The final model takes elements from the first two models. It preferences the individual student centered approach and the independence of the student's learning. In this model the student/s proposes their own design project (individual or group task). This is mapped to the 'learning outcomes' that students are expected to 'demonstrate' across one or more of the STEM areas. This proposal is formalized and refined into a learning agreement which describes the student's proposed project, their expected learning outcomes and the way through which they will demonstrate their learning (Brewer, Williams & Sher, 2007). This highly individualized learning approach is ideal for smaller cohorts. It requires intensive student consultation at times, but again it mirrors the expectations of real-life designers who often work in a collaborative and self managed way as they undertake design projects.

In the case of a school the projects may be individualized, or group projects. The teacher's role is to; negotiate and guide the student's learning, check-in and monitor their progress, tick off and evaluate their learning progressively (Schunk, 1990). This different model of pedagogy can initially be a challenge for both teachers and students but it can also produce some of the more outstanding results as excellent students excel without the limitation of the structured classroom to confine their learning and design activities (Figure 4). Other students will struggle with the freedom offered through this approach, and may initially require close assistance and support to work progressively through the process. The disadvantage of this approach may be that the unstructured nature of the projects may make some of the learning outcomes difficult or impossible for some students to demonstrate through their project. However over several projects, through-out the year, each student can demonstrate all of the learning from one or more of the STEM areas.

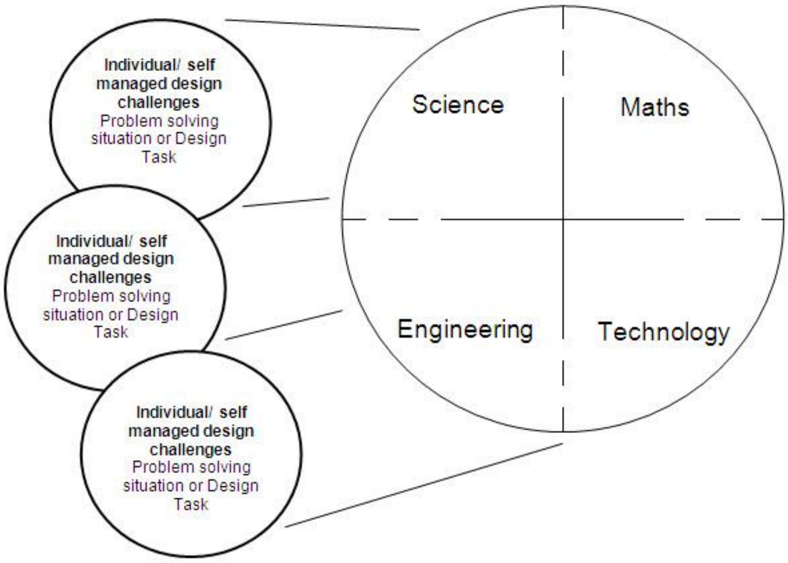

Figure 4: Using Student Led Projects as the Curriculum (Model 3)

5. Strengths and Weaknesses of the Proposed Models

All models have their strengths and weaknesses. The models presented in this paper are no different. It is important to acknowledge these attributes and deal with them appropriately. The table below outlines the strengths and weaknesses.

Table 1: Strengths and weaknesses of the proposed models

	Strengths	**Weaknesses**
The central project approach	A more coordinated approach that meets the curriculum needs of teachers while still actively engaging the students in their own learning Helps to ensure that the needs of each STEM curriculum domain are met. The central project provides a focus to integrate learning and make it more meaningful to students	The pre-selection of the design challenge by the teacher/s may engage students less than the self selection of their own task Focuses as much on the separateness of domains as it does on the integration of knowledge Limited project development time – may be seen as 'an add on' rather than an integrated aspect of practice
Student Led Projects Approach	Provides an opportunity for students to self select their own project of interest to themselves – maximizes engagement Makes the students more responsible for	Presents a significant organizational challenge as student groups or individuals may be completing a wide variety of different projects

	their own learning Presents an opportunity for a science/technology fair to share projects at the completion of the unit	Limited project development time – may be seen as 'an add on' rather than an integrated aspect of practice
Using student designed projects as the curriculum	Makes the project central to the learning of the students and places the emphasis on students to become independent, self directed learners Places the teacher in the role of project manager, or overseer of the student's projects – perhaps a mentor or coach Maximum project development time Project management skills developed	Is the most organizationally challenging - as student groups or individuals may be completing a wide variety of different projects relatively independently A wide variety of learning outcomes are possible – some areas or concepts in STEM may not initially be addressed Some students may struggle due to a lack of structure

6. Developing Problem Solving Situations or Design Challenge

The key to creating engaging STEM activities is the proper design and implementation of an effective 'integrating', problem-based activity. This provides the context for student's learning and enables the meaningful integration of knowledge into a solution or product that demonstrates student's learning across the different domains of STEM.

Such tasks can be written in a very 'closed' or 'open' manner. (Berry, 1998) Closed design tasks tend to offer students more limitations and less scope for creativity whereas 'open' design tasks or 'design challenges' tend to be more open to the interpretation of the students allowing for the development of a more diverse range of products and solutions. Open design challenges provide more scope for creativity and student problem solving. However there are times when teachers will choose to use more directed or closed design tasks. These focus the attention of students on particular problems and issues which may align with particular content or information that teachers want students to address – for example design and create 'a self-closing magnetic locking system for a door' . This is closed because it specifies the type of device to be created and how it will be used. A more open alternative, that would still provide the opportunity for students to address many of the same conceptual knowledge would be to say' using electro magnets design and develop a device that can be used either around the house or at school'. In the second case a broad range of final products and ideas might be developed. By keeping the design challenge open the students are challenged to become more independent learners, but can also be more motivated as they pursue their own design ideas and create a design or product which demonstrates a combination of their STEM knowledge.

7. Conclusion

The separation of subjects has traditionally occurred in school and university settings (Herschbach, 2011). However, this abstract way of learning ignores the real-life problem-solving contexts that exist and the knowledge gained is often not retrievable in real-life, problem-solving contexts (Sanders, 2009). Using PBL projects that integrate science, technology, engineering and mathematics fosters a student-directed inquiry and has been effective in increasing student motivation and problem solving skills (Blumenfeld et al., 1991). Student teams investigate challenging hands-on real-world projects that integrate STEM knowledge and can assist students develop their problem solving abilities and knowledge integration (Thurgut, 2008). By integrating the STEM disciplines teachers are able to implement engaging hands-on learning opportunities that mirror real-world projects.

There has been criticism of the PBL approach as it can be difficult to implement (Herschbach, 2011). This paper offers three different models of implementation of PBL integrating STEM in the classroom. Each model has advantages and disadvantages for classroom implementation, however each model could be used effectively to integrate the STEM disciplines in a project-based learning experience.

This paper has argued that there exists several compelling reasons for the interdisciplinary delivery and teaching of the STEM disciplines. In others words it suggests that a cohesive Science, Technology, Engineering and Mathematics program offers increased opportunity for a quality curriculum delivery, meaningful and real life learning, and better real world application by the students of their knowledge following the course. It suggests that such programs can be configured and delivered through an interdisciplinary planning and implementation team of teachers. These teachers can plan their work based upon 'real-life' open-ended design tasks, that challenge the students to use a combination of logical thinking, creative enquiry and practical hands-on problem solving activities to develop their design solutions. That through these open-ended design tasks powerful learning can occur which influences students understanding of themselves as 'designers and creators' of technological products as well as developing quality and lasting learning outcomes across the STEM discipline. Three models have been proposed for the implementation of STEM at a school or university level. How these are implemented depends on the schools individual approach and their educational philosophy, but readers should be assured that any one of these models will be educationally engaging for students and help to refine and develop the STEM skills, capabilities and knowledge.

References

Bencze, J.L. (2010). Promoting student-led science and technology projects in elementary teacher education: Entry into core pedagogical practices through technological design. International Journal of Technology and Design Education, 20(1), 43-62.

Berry, M. (1998) Exploring Technology : activities for the middle and upper primary teacher. Band B. Sydney : McGraw-Hill.

Blumenfeld, PC, Soloway, E, Marx, RW, Krajcik, JS, Guzdial, M & Palincsar, A 1991, Motivating project-based learning: sustaining the doing, supporting the learning, Educational Psychologist, vol. 26, no. 3 & 4, pp. 369-398.

Brewer, G. J., Williams, A. P., & Sher, W. D. (2007). Utilising learning contracts to stimulate student ownership of learning. Paper presented at the 18th Conference of the Australasian Association for Engineering Education, Melbourne.

Brophy, S., Klein, S., Portsmore, M., Rogers, C. (2008). Advancing engineering education in P-12 classrooms. Journal of Engineering Education, 97(3) 369-387.

ChanLin, L. J. (2008). Technology integration applied to project-based learning in science. Innovations in Education and Teaching International, 45(1), 55–65.

Dean, D., & Kuhn, D. (2007). Direct instruction vs. discovery: The long view. Science Education, 91, 384-397.

Hargreaves, A., & Moore, S. (2000). Curriculum integration and classroom relevance: A study of teachers‘ practice. Journal of Curriculum and Supervision, 15(2), 89–112.

Herschbach, D. R. (2011). The STEM initiative: Constraints and challenges. Journal of Stem Teacher Education, 48(1), 96-122.

Hmelo-Silver, C. (2004). Problem-based learning: What and how do students learn? Educational Psychology Review, 16, 235–266.

Krajcik, J. S., Czeniak, C., & Berger, C. (1999). Teaching children science: A project-based approach. Boston: McGraw-Hill College.

Salomon, G., & Perkins, D. N. (1989). Rocky roads to transfer: Rethinking mechanisms of a neglected phenomenon. Educational Psychologist, 24(2), 113–142.

Sanders, M. (2009). STEM, STEM education, STEM mania. Technology Teacher, 68(4), 20–26.

Schunk, D. H. (1990). Goal setting and self-efficacy during self-regulated learning. Educational Psychologist, 25(1), 71-86.

Springer, L., Stanne, M. E., & Donovan, S. S. (1999). Effects of small-group learning on undergraduates in science, mathematics, engineering and technology: A meta-analysis. Review of Educational Research, 69(1), 21–51.

Williams, J. (2011). STEM education: Proceed with caution. Design and Technology Education: An International

Journal, 16(1), 26–35.

Yaşar, S., Baker, D., Robinson-Kurpius, S., Krause, S., & Roberts, C. (2006). Development of a survey to assess K-12 teachers' perceptions of engineers and familiarity with teaching design, engineering, and technology. Journal of Engineering Education, 95(3), 205-216.

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1. Introduction

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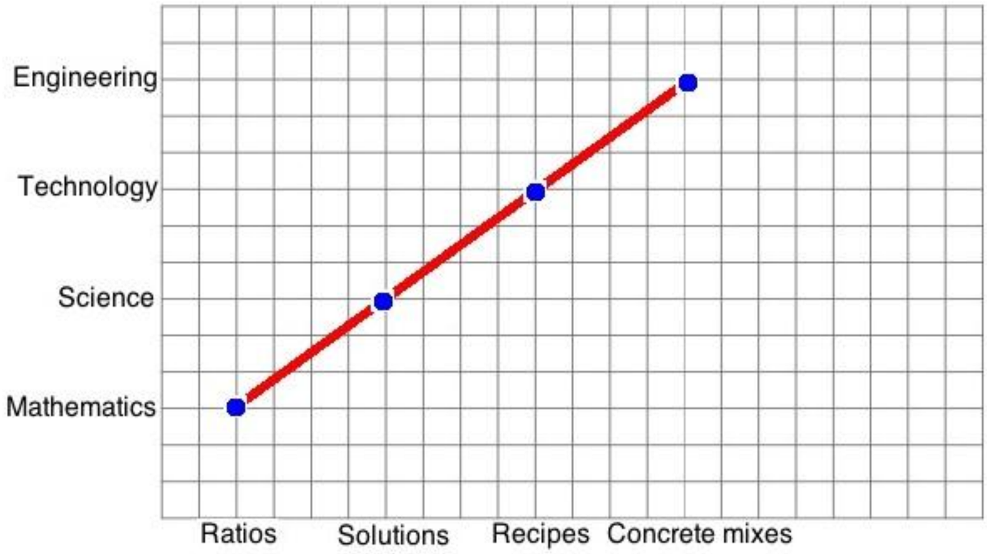

Figure 1. Inter-relationship between concepts across STEM disciplines

Such connections between these disciplines need to be further harnessed. One alternative is a project-based learning (PBL) approach that focuses on practical activities where student teams work together on projects and develop a shared understanding (ChanLin, 2008; Krajcik, Czeniak, & Berger, 1999). PBL is a learner-centered approach where students are encouraged to integrate knowledge, take responsibility for their learning and work in teams to investigate real issues and construct products. PBL has been shown to be effective in increasing motivation and higher order thinking skills (Blumenfeld et al., 1991). A PBL approach can facilitate the integration of STEM knowledge and assist students to develop their problem solving abilities and knowledge integration. Integrating STEM into a PBL approach can help students understand the relationship between their learning and the real-world applications (Hmelo-Silver 2004; Salomon & Perkins 1989).

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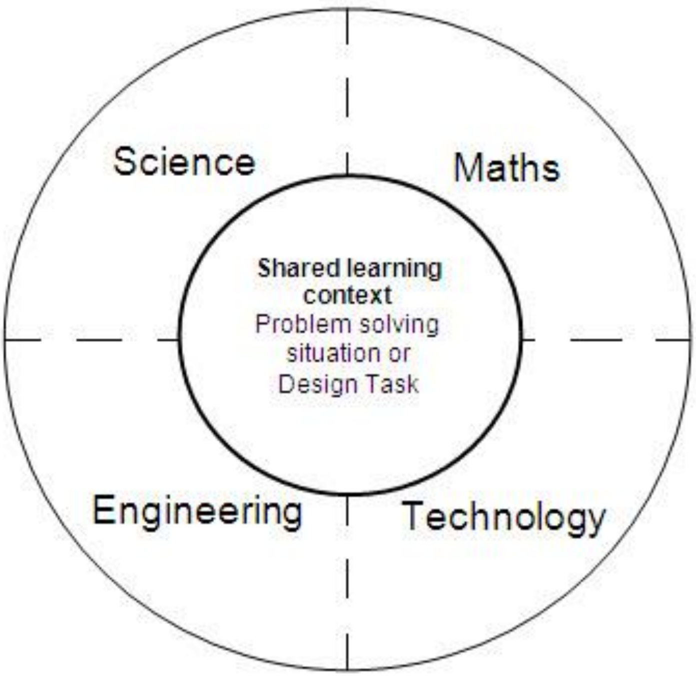

Figure 2: The Central Project Approach (Model 1)

3. Second Model: Student Led Projects Approach

While the first approach to the integration of STEM focuses on a teacher driven approach, where a team of teachers pre-plan the design task, the second is more student led. In this model the students are asked to design and develop their own projects (Bencze, 2010), each offering an opportunity to explore concepts and ideas associated with STEM concepts. This is a more open project model where the students have a range of creative design options (Figure 3). Typically the students are lead through a simple design process so that they understand the fundamental processes that they will need to follow when undertaking their own project. The students are then asked to form teams and to work on defining a project of interest to them. They then undertake the design process to design and realize their product. Various levels of guidance may be offered to the students to shape their thinking. For example, they may be asked to design and develop a time saving device for use around the house or to design and develop a product which might be used by a person with a disability. This still means that the students will be applying a range of concepts relating to the areas of STEM but the content that might be taught in class would not necessarily relate to the designs that the students are creating. This can be done as an integrated project where teams are developed a combination of students from different subjects relating to STEM or as a series of stand-alone projects where the students from different STEM areas work separately at different times, but perhaps come together to share their final design products across the STEM area – something like a science fair.

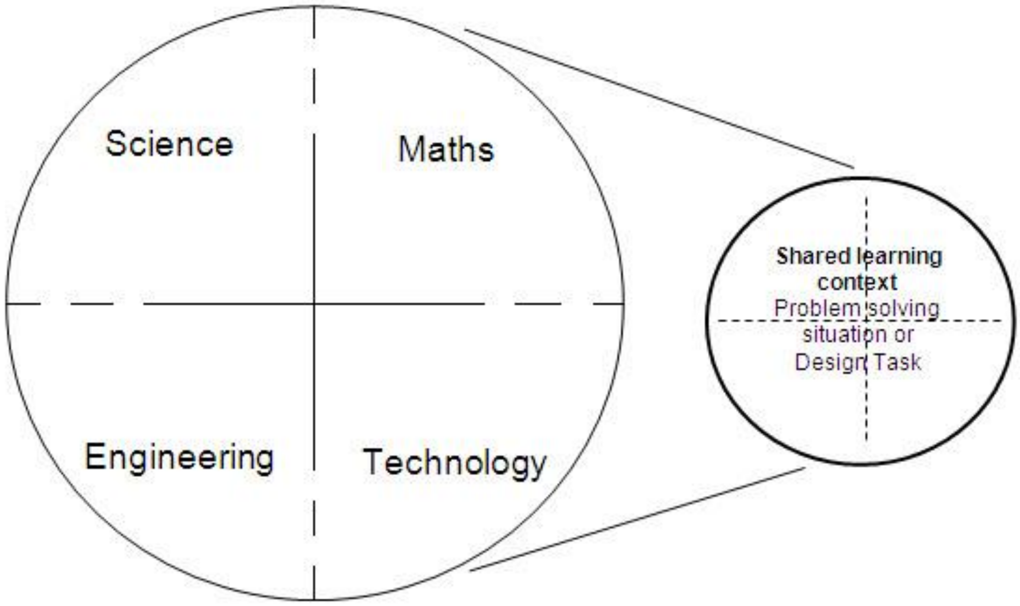

Figure 3: Student Led Projects Approach (Model 2)

4. Third Model – Using Student Led Projects as the Curriculum

The final model takes elements from the first two models. It preferences the individual student centered approach and the independence of the student's learning. In this model the student/s proposes their own design project (individual or group task). This is mapped to the 'learning outcomes' that students are expected to 'demonstrate' across one or more of the STEM areas. This proposal is formalized and refined into a learning agreement which describes the student's proposed project, their expected learning outcomes and the way through which they will demonstrate their learning (Brewer, Williams & Sher, 2007). This highly individualized learning approach is ideal for smaller cohorts. It requires intensive student consultation at times, but again it mirrors the expectations of real-life designers who often work in a collaborative and self managed way as they undertake design projects.

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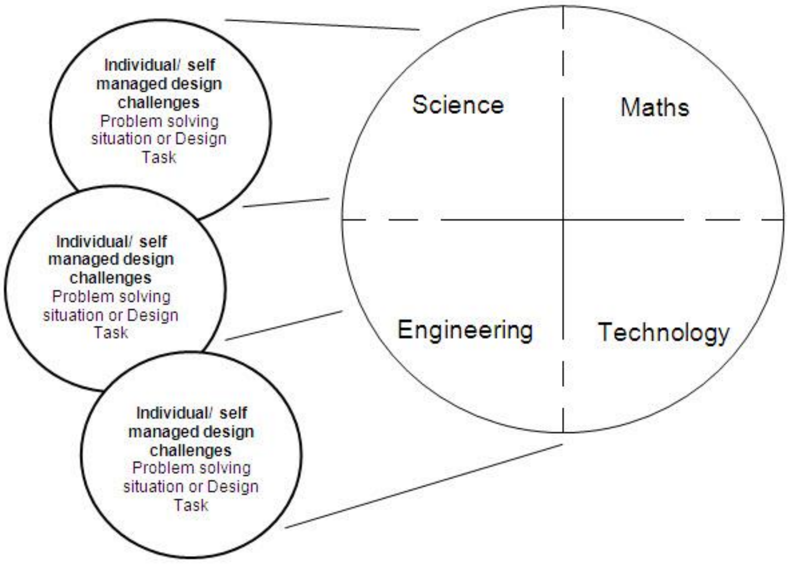

Figure 4: Using Student Led Projects as the Curriculum (Model 3)

5. Strengths and Weaknesses of the Proposed Models

All models have their strengths and weaknesses. The models presented in this paper are no different. It is important to acknowledge these attributes and deal with them appropriately. The table below outlines the strengths and weaknesses.

Table 1: Strengths and weaknesses of the proposed models

	Strengths	**Weaknesses**
The central project approach	A more coordinated approach that meets the curriculum needs of teachers while still actively engaging the students in their own learning Helps to ensure that the needs of each STEM curriculum domain are met. The central project provides a focus to integrate learning and make it more meaningful to students	The pre-selection of the design challenge by the teacher/s may engage students less than the self selection of their own task Focuses as much on the separateness of domains as it does on the integration of knowledge Limited project development time – may be seen as 'an add on' rather than an integrated aspect of practice
Student Led Projects Approach	Provides an opportunity for students to self select their own project of interest to themselves – maximizes engagement Makes the students more responsible for	Presents a significant organizational challenge as student groups or individuals may be completing a wide variety of different projects

	their own learning Presents an opportunity for a science/technology fair to share projects at the completion of the unit	Limited project development time – may be seen as 'an add on' rather than an integrated aspect of practice
Using student designed projects as the curriculum	Makes the project central to the learning of the students and places the emphasis on students to become independent, self directed learners Places the teacher in the role of project manager, or overseer of the student's projects – perhaps a mentor or coach Maximum project development time Project management skills developed	Is the most organizationally challenging - as student groups or individuals may be completing a wide variety of different projects relatively independently A wide variety of learning outcomes are possible – some areas or concepts in STEM may not initially be addressed Some students may struggle due to a lack of structure

6. Developing Problem Solving Situations or Design Challenge

The key to creating engaging STEM activities is the proper design and implementation of an effective 'integrating', problem-based activity. This provides the context for student's learning and enables the meaningful integration of knowledge into a solution or product that demonstrates student's learning across the different domains of STEM.

Such tasks can be written in a very 'closed' or 'open' manner. (Berry, 1998) Closed design tasks tend to offer students more limitations and less scope for creativity whereas 'open' design tasks or 'design challenges' tend to be more open to the interpretation of the students allowing for the development of a more diverse range of products and solutions. Open design challenges provide more scope for creativity and student problem solving. However there are times when teachers will choose to use more directed or closed design tasks. These focus the attention of students on particular problems and issues which may align with particular content or information that teachers want students to address – for example design and create 'a self-closing magnetic locking system for a door' . This is closed because it specifies the type of device to be created and how it will be used. A more open alternative, that would still provide the opportunity for students to address many of the same conceptual knowledge would be to say' using electro magnets design and develop a device that can be used either around the house or at school'. In the second case a broad range of final products and ideas might be developed. By keeping the design challenge open the students are challenged to become more independent learners, but can also be more motivated as they pursue their own design ideas and create a design or product which demonstrates a combination of their STEM knowledge.

7. Conclusion

The separation of subjects has traditionally occurred in school and university settings (Herschbach, 2011). However, this abstract way of learning ignores the real-life problem-solving contexts that exist and the knowledge gained is often not retrievable in real-life, problem-solving contexts (Sanders, 2009). Using PBL projects that integrate science, technology, engineering and mathematics fosters a student-directed inquiry and has been effective in increasing student motivation and problem solving skills (Blumenfeld et al., 1991). Student teams investigate challenging hands-on real-world projects that integrate STEM knowledge and can assist students develop their problem solving abilities and knowledge integration (Thurgut, 2008). By integrating the STEM disciplines teachers are able to implement engaging hands-on learning opportunities that mirror real-world projects.

There has been criticism of the PBL approach as it can be difficult to implement (Herschbach, 2011). This paper offers three different models of implementation of PBL integrating STEM in the classroom. Each model has advantages and disadvantages for classroom implementation, however each model could be used effectively to integrate the STEM disciplines in a project-based learning experience.

This paper has argued that there exists several compelling reasons for the interdisciplinary delivery and teaching of the STEM disciplines. In others words it suggests that a cohesive Science, Technology, Engineering and Mathematics program offers increased opportunity for a quality curriculum delivery, meaningful and real life learning, and better real world application by the students of their knowledge following the course. It suggests that such programs can be configured and delivered through an interdisciplinary planning and implementation team of teachers. These teachers can plan their work based upon 'real-life' open-ended design tasks, that challenge the students to use a combination of logical thinking, creative enquiry and practical hands-on problem solving activities to develop their design solutions. That through these open-ended design tasks powerful learning can occur which influences students understanding of themselves as 'designers and creators' of technological products as well as developing quality and lasting learning outcomes across the STEM discipline. Three models have been proposed for the implementation of STEM at a school or university level. How these are implemented depends on the schools individual approach and their educational philosophy, but readers should be assured that any one of these models will be educationally engaging for students and help to refine and develop the STEM skills, capabilities and knowledge.

References

Bencze, J.L. (2010). Promoting student-led science and technology projects in elementary teacher education: Entry into core pedagogical practices through technological design. International Journal of Technology and Design Education, 20(1), 43-62.

Berry, M. (1998) Exploring Technology : activities for the middle and upper primary teacher. Band B. Sydney : McGraw-Hill.

Blumenfeld, PC, Soloway, E, Marx, RW, Krajcik, JS, Guzdial, M & Palincsar, A 1991, Motivating project-based learning: sustaining the doing, supporting the learning, Educational Psychologist, vol. 26, no. 3 & 4, pp. 369-398.

Brewer, G. J., Williams, A. P., & Sher, W. D. (2007). Utilising learning contracts to stimulate student ownership of learning. Paper presented at the 18th Conference of the Australasian Association for Engineering Education, Melbourne.

Brophy, S., Klein, S., Portsmore, M., Rogers, C. (2008). Advancing engineering education in P-12 classrooms. Journal of Engineering Education, 97(3) 369-387.

ChanLin, L. J. (2008). Technology integration applied to project-based learning in science. Innovations in Education and Teaching International, 45(1), 55–65.

Dean, D., & Kuhn, D. (2007). Direct instruction vs. discovery: The long view. Science Education, 91, 384-397.

Hargreaves, A., & Moore, S. (2000). Curriculum integration and classroom relevance: A study of teachers‘ practice. Journal of Curriculum and Supervision, 15(2), 89–112.

Herschbach, D. R. (2011). The STEM initiative: Constraints and challenges. Journal of Stem Teacher Education, 48(1), 96-122.

Hmelo-Silver, C. (2004). Problem-based learning: What and how do students learn? Educational Psychology Review, 16, 235–266.

Krajcik, J. S., Czeniak, C., & Berger, C. (1999). Teaching children science: A project-based approach. Boston: McGraw-Hill College.

Salomon, G., & Perkins, D. N. (1989). Rocky roads to transfer: Rethinking mechanisms of a neglected phenomenon. Educational Psychologist, 24(2), 113–142.

Sanders, M. (2009). STEM, STEM education, STEM mania. Technology Teacher, 68(4), 20–26.

Schunk, D. H. (1990). Goal setting and self-efficacy during self-regulated learning. Educational Psychologist, 25(1), 71-86.

Springer, L., Stanne, M. E., & Donovan, S. S. (1999). Effects of small-group learning on undergraduates in science, mathematics, engineering and technology: A meta-analysis. Review of Educational Research, 69(1), 21–51.

Williams, J. (2011). STEM education: Proceed with caution. Design and Technology Education: An International

Journal, 16(1), 26–35.

Yaşar, S., Baker, D., Robinson-Kurpius, S., Krause, S., & Roberts, C. (2006). Development of a survey to assess K-12 teachers' perceptions of engineers and familiarity with teaching design, engineering, and technology. Journal of Engineering Education, 95(3), 205-216.